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1 Method for Assessing the Integrity of a Structure

2

3 The present invention relates to a method for  
4 assessing the integrity of a structure. The method  
5 according to the present invention involves the  
6 measurement of the dimensions of the structure and  
7 the loading and thereafter analysing the results of  
8 those measurements in order to calculate a value for  
9 the integrity of the structure.

10

11 In the process industry, one of the biggest sources  
12 of failures and shutdown for process plants is in  
13 pressurised piping and vessel systems. In the prior  
14 art, systems are known which monitor and assess  
15 plants in order to be able to predict a failure.  
16 According to the prior art, the wall thickness of  
17 structures, such as piping, is simply monitored in  
18 order to perform simple calculations and to predict  
19 a trend, for instance in the wear and/or the  
20 corrosion of such a structure. Alternatively,  
21 machinery-based corrosion and vibration monitoring  
22 systems are used. These systems are grossly

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1 inaccurate as over 85% of failures occur at non-  
2 straight pipe areas, due to structural loadings,  
3 corrosion/erosion, fatigue, pulsation or vibration  
4 ("Hydrocarbon" magazine). The monitoring and  
5 assessment technologies according to the prior art  
6 are based on "risk analysis". These systems use  
7 probability to estimate failure, and in doing so  
8 predict suitable inspection intervals. An important  
9 disadvantage of such an approach is that these  
10 systems do not use real-time measurements in order  
11 to calculate real-time load and load changing  
12 mechanisms.

13  
14 A system for monitoring a pipe segment for instance  
15 is known from the European Patent Application EP  
16 0358994. The method according to EP 0358994 is  
17 adapted to measure a corrosion/erosion trend. The  
18 system is confined to the change in the main pipe  
19 wall thickness to predict the future thickness of  
20 the pipe wall. According to this document the  
21 emphasis is on measuring the corrosion/erosion rate  
22 and using statistical techniques to predict future  
23 rates and trends. The estimated stress in a pipe  
24 wall is calculated using the following equation:

25  
26 Stress =  $\frac{\text{pressure} \times \text{radius}}{\text{thickness}}$  x estimated factor  
27

28  
29 This equation only calculates pressure loading in  
30 straight pipes. No other loadings are considered.  
31 As the thickness decreases there is a danger of  
32 pipewall rupture. Therefore the information is used

1 in order to predict the maximum time interval before  
2 the next inspection of the pipe welds. The  
3 information collected according to EP0358994, in  
4 practice, is not very helpful, as very few plant  
5 failures are caused by main pipewall rupture. This  
6 means that the information collected by means of  
7 EP0358994 has only limited value.

8  
9 US-A- 48523397 discloses a procedure for measuring  
10 material properties of a tructure. The method is  
11 used to test the material properties of a failed  
12 structure. The results are used to determine if the  
13 remaining structure is safe to dismantle or even  
14 partially remain in service. This system does not  
15 indicate in any way, how to measure the loads or  
16 geometry of any system, let alone how to further  
17 predict the Integrity of such a structure. This  
18 method can only be used as a destructive method of  
19 determining material behaviour such as a Stress-  
20 Strain Curve and Fracture Toughness.

21  
22 US-2001-040997 discloses a method for tracking  
23 moving objects such as skin. It is designed for  
24 Motion Tracking and bears no relevance to Integrity  
25 Monitoring. The fact that it uses a Finite Element  
26 Analysis technique is irrelevant because this method  
27 is used for many applications. The iterative  
28 approach used according to D2 is to re-mesh the  
29 Finite Element Model to simulate the skin motion and  
30 is an iterative approach so as to allow the mesh to  
31 move, thus tracking the motion. It is not modelling  
32 a whole structure. It is not modelling any loadings

1 that would be relevant, nor does it measure systems  
2 characteristics and use these to predict its  
3 Integrity. It simply teaches that a localised Finite  
4 Element Grid can be used to track motion.

5  
6 Additionally, according to the prior art it is known  
7 to use acoustic pulsation, vibration and condition  
8 monitoring in order to monitor and assess the  
9 integrity of a structure. The disadvantage of those  
10 techniques is the fact that those techniques are  
11 both specialist tasks and extremely expensive.  
12 Because of the high costs involved with those  
13 techniques normally these techniques are only  
14 undertaken if failure is expected or has occurred.

15  
16 In view of the disadvantages and limitations of the  
17 methods for assessing the integrity of a structure  
18 according to the prior art, it is an object of the  
19 present invention to provide a method according to  
20 the introduction wherein load-changing mechanisms  
21 and dimension changing mechanisms, as they occur,  
22 are taken into account in the calculations of the  
23 integrity of the structure.

24  
25 To obtain these objects, the method according to the  
26 present invention comprises the steps of:

- 27
- 28 i) collecting data relating to the initial
  - 29 dimensions of the structure,
  - 30 ii) creating a computer model of the structure,
  - 31 iii) collecting load data relating to the estimated
  - 32 load on the structure,

- 1     iv)   analysing the structure, using the computer  
2           model of the structure and the load data, in  
3           order to define areas which are subject to  
4           relatively high stresses,  
5     v)    measuring, after a time interval, the  
6           dimensions of the structure in high stress  
7           areas,  
8     vi)   updating the computer model of the structure,  
9           using the results of step v),  
10    vii) re-analysing the structure, using the updated  
11          computer model and the load data, in order to  
12          calculate a value for the integrity of the  
13          structure.

14  
15    In the present description the wording "computer  
16    model" is used. The wording "computer model" refers  
17    to a data set representing a structure, which data  
18    set can be analysed by means of an appropriate  
19    finite element analysis technology. By means of  
20    this finite element analysis technology the strains  
21    and stresses occurring in the structure can be  
22    calculated.

23  
24    In the present description reference is made to "a  
25    value for the integrity of the structure". The  
26    wording "value for the integrity of a structure"  
27    refers to whether a structure is "fit for service"  
28    or not. When the value for the integrity of a  
29    structure is calculated, it is assessed whether the  
30    structure is fit to perform its normal tasks. That  
31    means that the value for the integrity of a  
32    structure can refer to a minimum wall thickness, a

1 maximum stress in the material of the wall, a  
2 maximum strain in the material of a wall, or similar  
3 feature.

4  
5 According to the present invention data relating to  
6 the initial dimensions of a structure are collected.  
7 These data are used to create a computer model of  
8 the structure. That means that it is possible to  
9 use a finite element method in order to calculate  
10 strains and stresses in the structure. Thereafter  
11 data is collected relating to the estimated load on  
12 the structure. By means of the finite element  
13 method the structure can then be analysed, using  
14 both the computer model and the load data. The  
15 result of this analysis is that individual areas can  
16 be defined which are subject to relatively high  
17 stresses. Because of the fact that the high stress  
18 areas are identified, it is clear in which areas of  
19 the structure future problems can be expected.

20  
21 If the results of the analysis of the structure  
22 reveal that the strains and stresses in the  
23 structure are within safety limits, the structure  
24 thereafter can be used for its normal purpose.  
25 After a set time interval the dimensions of the  
26 structure will be measured in the high load areas.  
27 Because of the fact that high load areas have been  
28 defined, the amount of measurements can be limited.  
29 That means that the actual measurement of the  
30 dimensions of the structure in the high load areas  
31 involves relatively limited effort.

1 Using the measured dimensions of the structure it is  
2 then possible to update the computer model and to  
3 re-analyse the structure. This calculation will  
4 result in an updated value for the integrity of the  
5 structure. This means that the method according to  
6 the present invention presents an efficient and  
7 effective method for assessing the integrity of a  
8 structure.

9  
10 According to the present invention the method may  
11 further comprise the step of:

12  
13 viii) repeating one or more times steps v), vi) and  
14 vii).

15  
16 According to the present invention it is possible to  
17 continuously measure the dimensions of the structure  
18 in high load areas. Steps v), vi) and vii) can be  
19 repeated after a set time interval, which time  
20 interval may be dependent on the calculated value  
21 for the integrity of the structure in a former  
22 analysis.

23  
24 According to the present invention the method may  
25 comprise the further step of:

26  
27 ix) visualising the results of vii).

28  
29 The method according to the present invention is  
30 suitable for continuously assessing the integrity of  
31 a structure. In order to facilitate the review of  
32 the outcome of the assessment, the results of the

1 calculations leading to the value for the integrity  
2 of the structure can be presented, for instance, in  
3 a table. This table can be presented to a plant  
4 manager who thereafter can take necessary actions,  
5 if needed.

6

7 According to the present invention the method may  
8 comprise the further steps of:

9

10 x) measuring the actual load on the structure,

11

12 xi) updating the data relating to the load on the  
13 structure, and thereafter

14

15 xii) re-analysing the structure, using the computer  
16 model and the updated load data, in order to  
17 calculate a value for the integrity of the  
18 structure.

19

20 The method according to the present invention cannot  
21 only be used for assessing the actual dimensions of  
22 the structure, the method is also suitable for  
23 measuring the actual load on the structure and using  
24 the results of those measurements in order to refine  
25 the calculations of the value for the integrity for  
26 the structure.

27

28 According to the present invention the method may  
29 comprise the further step of xiii) repeating one or  
30 more times steps x), xi) and xii).

31 Moreover, the method may comprise the further step  
32 of:

1  
2 xiv) visualising the steps of step xii).

3  
4 According to the present invention it is  
5 advantageous that the method comprises the steps of  
6 installing, after step iv), in high stress areas, a  
7 first set of sensors for measuring the dimensions of  
8 the structure in said high stress areas. Moreover,  
9 it is advantageous that the method comprises the  
10 step of installing, after step iv), in high stress  
11 areas, a second set of sensors for measuring the  
12 load on the structure in said high stress areas.

13  
14 The advantage of these measures is the fact that the  
15 data relating to the dimensions of the structure and  
16 the actual load on the structure can be collected  
17 automatically. In order to process the collected  
18 data in real-time it is an advantage that the method  
19 comprises the step of connecting the sensors to  
20 processing means, such as a computer, for  
21 transmitting data from the sensors to the processing  
22 means in real-time.

23  
24 The method according to the present invention can be  
25 used for new systems. The method, however, is also  
26 suitable for structures which already have been used  
27 during a certain time frame. In those cases it is  
28 advantageous that the method comprises the step of  
29 prior to step iv), collecting data relating to known  
30 defects of the structure and thereafter using said  
31 defect-data, the computer model of the structure and

1 the load-data for defining areas which are subject  
2 to relatively high loads.

3

4 By adding the data relating to known defects of the  
5 structure the calculation of high load areas in the  
6 structure can be refined. Deterioration and growth  
7 of the defects can then be measured and analysed.

8

9 In case there are no known defects, it is possible  
10 that the method comprises the step of prior to step  
11 iv), estimating the minimum size of defect in the  
12 structure and thereafter using said estimated  
13 defect-data, the computer model of the structure and  
14 the load-data for defining areas which are subject  
15 to relatively high loads. Moreover, it is possible  
16 that the minimum size of the defect is estimated to  
17 be equal to the precision the measurement equipment,  
18 used for measuring the dimensions of the structure.

19

20 When the structure, to be analysed, is used for a  
21 certain time period, and the load history on the  
22 structure is known, it is possible that the method  
23 comprises the step of prior to step iv), collecting  
24 data relating to the load-history on the structure  
25 and thereafter using said load-history, the computer  
26 model of the structure and the load-data for  
27 defining areas which are subject to relatively high  
28 loads. Using this extra step of collecting data  
29 relating to the load-history means that initial  
30 calculations of high-load areas can be refined.

31

1 The invention also relates to a processing  
2 arrangement for assessing the integrity of a  
3 structure, provided with processing means, such as a  
4 computer, for using data relating to the dimensions  
5 of the structure and the load on the structure in a  
6 calculation of a value representing the integrity of  
7 the structure, wherein the processing arrangement is  
8 provided with sensors to measure data relating to  
9 the dimensions of the structure and the load on the  
10 structure, the sensors being adapted to transmit  
11 said data in real-time, wherein the processing means  
12 are provided with receiving means for receiving said  
13 data and wherein the processing means are adapted to  
14 analyse the data in order to update the calculation  
15 of the value representing the integrity of the  
16 structure.

17  
18 Preferably the processing arrangement is provided  
19 with representation means for visualising the  
20 results of the calculation of the value for the  
21 integrity of the structure.

22  
23 According to the invention it is possible that the  
24 sensors used in the processing arrangement are  
25 adapted to measure pressure exerted on the  
26 structure, environmental loads, temperature,  
27 mechanical loading on the structure, fluid loading  
28 on the structure, vibration or acceleration  
29 experienced by the structure.

30

1 The invention also relates to a structure, such as a  
2 plant, provided with a processing arrangement as  
3 described above.

4  
5 The method according to the present invention can be  
6 entirely controlled by a suitable computer program  
7 after being loaded by the processing arrangement.  
8 Therefore, the invention also relates to a computer  
9 program product comprising data and instructions  
10 that after being loaded by a processing arrangement  
11 provides said arrangement with the capacity to carry  
12 out a method as defined above.

13  
14 Also a data carrier provided with such a computer  
15 program is claimed.

16  
17 Below, the invention will be explained in detail  
18 with reference being made to the drawings. The  
19 drawings are only intended to illustrate the  
20 invention and not to limit its scope which is only  
21 defined by the dependent claims.

22  
23 Fig 1 shows a schematic overview of a processing  
24 arrangement for assessing the integrity of a vessel.

25 Fig 2 shows a visual representation of the  
26 calculations of a value for the integrity of a  
27 structure.

28  
29 Fig 3 shows a schematic overview of the software  
30 used according to the present invention.

31

1 Fig 4 shows a diagram indicating the relation  
2 between inspection costs, the number of inspections  
3 and the corresponding risk.

4  
5 In Fig 1 a schematic overview is shown of a  
6 processing arrangement 10 for assessing the  
7 integrity of a vessel. In order to assess the  
8 integrity of the vessel 20, at an initial stage a  
9 computer model will be created representing the  
10 dimensions of the vessel 20. When creating said  
11 computer model the presence of corroded areas 21 and  
12 the presence of flaws, pits and cracks 22 can be  
13 taken into account. The processing arrangement 10  
14 comprises sensors 11 which are installed in high  
15 load areas of the vessel 20. In Fig 1 only one  
16 sensor is shown. In practice, several sensors will  
17 be installed in order to allow a good overview of  
18 the condition, strains and stresses in the vessel  
19 20. The sensor 11 by means of a line 12 is  
20 connected to a data logger 13. The data logger 13  
21 is connected to processing means 14, such as a  
22 computer. The computer 14 is provided with suitable  
23 software in order to process the data generated by  
24 the data logger 13. A possible architecture for the  
25 software to be used in the computer 14 is described  
26 with reference to Fig 3. By means of the sensor 11  
27 the actual dimensions of the vessel 20 and the load  
28 exerted on the vessel can be continuously measured  
29 and can be forwarded to the computer 14. The  
30 updated information sent to the computer 14 can be  
31 used to constantly reanalysis the structure and

1 recalculate values for the integrity of the  
2 structure.

3

4 The results of the calculations can be visualised,  
5 for instance by means of a document centre 15. The  
6 document centre 15 can be used, for instance, for  
7 printing tables and overviews (see Fig 2), in order  
8 to inform the responsible plant manager.

9

10 In Fig 1 reference numbers 23 and 24 are used for a  
11 graphic representation of flaws, pits and cracks  
12 which can be present in the vessel wall. During the  
13 lifetime of the vessel the actual size of such  
14 flaws, pits and cracks(in 3-d) will be used in  
15 calculations of the value for the integrity of the  
16 structure. That means that according to the present  
17 invention no estimations of trends are used. The  
18 actual sizes of the flaws, pits and cracks in the  
19 system will be used when calculating the  
20 representative value for the integrity of the  
21 structure.

22

23 According to the present invention it is possible to  
24 add a warning system. This warning system could  
25 produce a warning when the value for the integrity  
26 of the structure drops below a specific  
27 predetermined level. It is also possible to  
28 indicate on a visual representation the value for  
29 the integrity of the structure has dropped below a  
30 certain minimum.

31

1 In Fig 2 a possible outcome of the calculations are  
2 shown. According to the requirements of a user, the  
3 outcome of the calculations provides information on,  
4 but not limited to, the working pressure inside the  
5 vessel, the number of fatigue cycles to date, the  
6 number of fatigue cycles remaining, current  
7 corrosion rate, date until inspection is required,  
8 the current safety factor, current risk factors,  
9 etc. The visual representation of the outcome of  
10 the calculations of the value for the integrity of  
11 the structure can be tailored upon a user's request.  
12 The visual representation according to Fig 2  
13 provides a plant manager with a user-friendly  
14 overview of the integrity of a structure.

15  
16 In Fig 3 a schematic overview is given of a software  
17 program which can be used in the method and  
18 processing arrangement according to the present  
19 invention. Because of the fact that the software  
20 module provides an analysis system for plant real-  
21 time integrity assessment, the software module could  
22 be referred to as "Aspria". The software system is  
23 built up from several modules. The overall system  
24 will be referred to as "Integri-TECH".

25  
26 The layout of the software system is shown in Fig 3.  
27 The central part of the system is a so-called  
28 management system or core system. The core system  
29 manages and controls the components and will produce  
30 the visual representation as shown in Fig 2. The  
31 core system enables the different modules to work

1 together in order to produce a single outcome,  
2 representing the integrity of a structure.

3

4 The core system comprises an analysis tool (Smart  
5 FEA), which is a program based on finite element  
6 analysis technology. This module includes advanced  
7 error estimation techniques. The module contains  
8 the "as-built" model of the structure to be  
9 analysed, plus components and receives the regular  
10 measurement data. When receiving the measurement  
11 data this module will update the finite element  
12 model and will perform an advanced finite element  
13 analysis and thereafter passes the results to  
14 further modules.

15

16 The core system also comprises a module for  
17 assessment of a corrosion patch. This module can be  
18 referred to as "envelope corrosion patch assessment"  
19 (ECPA), which has been derived to assess the effects  
20 of patches of corrosion in the various regions of  
21 each structure to be analysed. The module generates  
22 an envelope of possible conditions that will allow  
23 the system to predict the earliest possible danger  
24 signs for each structure. The corrosion patches can  
25 be located and automatically updated every time a  
26 corrosion measurement is taken or can be  
27 automatically generated from measurement data,  
28 adaptively meshed and can be dynamically positioned  
29 anywhere on the structure to be analysed for  
30 detailed finite element analysis. The results of  
31 the analysis are modified to account for the most  
32 likely severe and emerging patch shape and where the

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1 results are becoming nearer to limiting values,  
2 recommendations are passed back through the system  
3 in order that the finite element analysis can modify  
4 the finite element mesh in order to re-analysis the  
5 system whereby the corrosion patches are included.

6  
7 The core system further comprises a corrosion  
8 trending analysis (CTA). This modules analyses the  
9 history and trends and the future effects of  
10 corrosion and erosion in the system. This module  
11 moreover builds up on a history of the effects and  
12 derives continually updating correlations to predict  
13 corrosion rates, patterns, etc in order to be used  
14 in a further statistical analysis module.

15  
16 In case the structure to be analysed is in a high  
17 temperature area, for instance in high energy piping  
18 systems, a creep assessment system (CAS) can be  
19 used. This module will analyse the temperature and  
20 time history of a certain structure. Thereafter a  
21 creep analysis of the system will be carried out to  
22 simulate the stress changes due to time dependent  
23 temperature effects in the piping system and will  
24 build up a history of the effects and derive  
25 continually updating correlations to predict creep  
26 rates, patterns etc for the statistical analysis  
27 module.

28  
29 In case the structure to be analysed is subject to  
30 acoustic pulsation, such as in gas compression  
31 systems, a further harmonic-acoustic simulator (HIS)  
32 can be used. This modules analyses the acoustic

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1 pulsations in the system by harmonic analysis to  
2 simulate the stress changes due to acoustic  
3 pulsations in the piping system. The history is  
4 then stored and trends are predicted for the future  
5 effects of acoustic pulsations in the system and the  
6 system builds up a history of the effects and  
7 derives continually updating correlations to predict  
8 cyclic stress patterns. These cyclic stress patterns  
9 can be used in a statistical analysis module.

10

11 In case the structure to be analysed is subject to  
12 transient fluid flow conditions, such as in pumping  
13 systems, the core system moreover uses a transient  
14 simulator (TS). This module analyses the transient  
15 fluid flow effects in the system by time history  
16 analysis to simulate the stress changes due to  
17 transient fluid flow effects in the piping system.  
18 The history is then stored and trends predicted for  
19 the future effects of transient fluid flow effects  
20 in the system and the system builds up a history of  
21 the effects and derives continually updating  
22 correlations to predict cyclic stress patterns.  
23 These cyclic stress patterns can be used in a  
24 statistical analysis module.

25

26 The core system moreover comprises a statistical  
27 analysis module. This module takes all of the  
28 piping system loading history, cyclic patterns,  
29 operational data, corrosion and erosion and B-Tech  
30 vibration data and trends. These data then are  
31 statistically analysed to provide realistic and  
32 meaningful loading for first time history data for

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1 the defect and fracture module. The same  
2 information can be used in a fatigue life prediction  
3 module to predict the remaining lifetime of the  
4 structure before shutdown or failure. Standard  
5 statistical analysis is then employed in the system.

6  
7 The core system moreover is provided with a module,  
8 adapted to receive "live measurements", including  
9 frequency data, measured live by accelerometers, at  
10 small bore branch connections. This module is  
11 referred to as "B-Tech". The B-Tech part of the  
12 system then performs extensive mathematical  
13 correlations, algorithms and techniques to predict  
14 the effect of the vibration and more importantly to  
15 predict the fatigue life for the analysed structure  
16 automatically from the measured data. The module,  
17 if needed, can alert the user and can prevent  
18 failure. Another important part of this module is  
19 that the module isn't only capable of predicting the  
20 fatigue life from vibration, but will also predict  
21 which vibration excitation will cause problems for  
22 each particular arrangement and will indicate these  
23 vibration excitation if that level of vibration is  
24 detected.

25  
26 Results of these calculations will then be passed to  
27 a further defect and fracture and FLP modules.

28  
29 The core system moreover is provided with a liquid  
30 sloshing simulator. This module performs the  
31 simulation and assessment of liquid sloshing that  
32 can take place when a vessel is located on a moving

1 object, such as a ship. Such liquid sloshing is  
2 very detrimental to the integrity of the vessel and  
3 can be catastrophic. Therefore it is most important  
4 to assess the exact effects of the sloshing on the  
5 integrity of the vessel. The liquid sloshing  
6 simulator is adapted to simulate sloshing and to  
7 predict the interaction of the sloshing with the  
8 pressure vessel or a ship wall. The response of  
9 these loadings to the ship (or a vehicle) motion is  
10 measured and the cyclic loading pattern is generated  
11 and passed through the finite element analysis  
12 system for dynamic stress analysis. This analysis  
13 is followed by a defect and fatigue analysis in  
14 order to verify the integrity of the structure.

15  
16 The core system moreover comprises a defect and  
17 fracture module. This module performs the fracture  
18 mechanics assessment. The system is adapted to  
19 monitor, analyse and assess the growth of any defect  
20 in the structure. The system integrity is then  
21 quantified in respect of limiting crack and flaw  
22 sizes that will affect the integrity. The location,  
23 size and type of any possible defect or arrangement  
24 of cumulative defects can be assessed and also  
25 postulated defect assessments can be carried out.  
26 For instance, every weld in a structure, is assessed  
27 and every range of defects is assessed at every  
28 weld.

29  
30 A further module present in the core system is the  
31 fatigue life prediction module (FLP). This system  
32 performs the fatigue life predictions.

1 The core system manages the various modules which  
2 are shown in Fig 3. The specific features of those  
3 six modules will be described below.

4  
5 Aspria (analysis system for plant real time  
6 integrity assessment) is an analysis, monitoring and  
7 assessment system that can be connected to any  
8 pressurised plant or structural system than can  
9 deteriorate by erosion, corrosion or general  
10 time/operation exposure and/or vibration. This  
11 module quantifies the system's integrity, assesses  
12 the effects of all loadings, stresses, defects and  
13 predicts inspection and repair intervals as well as  
14 plant life and safety. This is all done "on-line",  
15 "live" or as "continuous monitoring system".

16  
17 The Aspria module constantly measures geometric  
18 thickness values in piping systems effected by  
19 corrosion, erosion, vibration, etc. A detailed  
20 geometric update is performed and the unit, whether  
21 a piece of plant, such as pipework, a structure or  
22 similar, will undergo an automatic and complete  
23 finite element stress analysis using for instance  
24 Smart-FEA (see above) and advanced error estimation  
25 techniques to determine the degree of accuracy.  
26 Defects, cracks or corrosion patches will be  
27 thoroughly analysed automatically and a system  
28 fatigue life automatically calculated. This will  
29 lead to prescribed inspection and repair intervals,  
30 and a quantified plant life. All loadings,  
31 including process, mechanical and environmental  
32 loadings, will be included in the assessment. If

1 the structure is used on a ship, the loading will  
2 include sea motion.

3  
4 The second module which can be used in the software  
5 is Vecor (vessel corrosion analysis system for plant  
6 real time integrity assessment). Vecor is an  
7 analysis, monitoring and assessment system that can  
8 be connected to any pressure vessel, tank or storage  
9 system which can deteriorate by erosion, corrosion  
10 or general time/operation exposure and/or vibration.  
11 The system includes FPSO and ship movements and the  
12 liquid sloshing and fluid structural interaction  
13 effect of vessels on ships. Moreover Vecor will  
14 include acceleration effects. It quantifies the  
15 system and integrity, assesses the effects of all  
16 loadings, stresses defects etc and predicts  
17 inspection and repair intervals as well as plant  
18 life and safety. This is all done "on-line", "live"  
19 or as a continuous monitoring system. The Vecor  
20 system will constantly measure geometric thickness  
21 values in pressure vessels, exchangers and tanks  
22 affected by corrosion, erosion, vibration etc.  
23 Another item that Vecor can measure is the motion of  
24 a ship or a platform. A detailed geometric and  
25 loading update will then be performed and the  
26 structure will undergo an automatic and complete  
27 finite element stress analysis using for instance  
28 Smart-FEA (see above) and advanced error measurement  
29 techniques in order to determine the degree of  
30 accuracy. Liquid sloshing effect within the vessel  
31 will be simulated and assessed if appropriate (that  
32 means when a ship pitches, heaves and rolls).

1 Interaction effects of the liquid sloshing and the  
2 vessel structure response will also be assessed.  
3 Defects, cracks or corrosion patches will be  
4 thoroughly analysed automatically and a system  
5 fatigue life automatically produced. This will lead  
6 to prescribed inspection and repair intervals, plus  
7 quantified plant life. All loadings, including  
8 process, mechanical and environmental loadings will  
9 be included in the assessments, including (if  
10 appropriate) sea motion.  
11 A further module to be used in the system is HEP-  
12 TECH (high energy piping technology). HEP-TECH is  
13 an analysis monitoring and assessment system which  
14 can be connected to high energy or high temperature  
15 piping systems in power stations or other markets,  
16 where deterioration by creep, support load  
17 variation, load and stress redistribution, high  
18 temperature effects or general time/operation  
19 exposure and/or vibration occurs. It quantifies the  
20 system integrity, assesses the effects of all  
21 support behaviour, loadings, stresses, defects and  
22 predicts inspection and repair intervals as well as  
23 plant life and safety. This is all done "on-line",  
24 "live" or as "continuous monitoring system. The  
25 HEP-TECH will constantly measure support load values  
26 effected by deterioration and load redistribution  
27 due to high temperatures of creep. A detailed load  
28 update will then be performed and the pipework will  
29 then undergo an automatic and complete finite  
30 element stress analysis and advanced error  
31 estimation techniques to determine the degree of  
32 accuracy. The system will be assessed and the load

1 corrections required highlighted for adjustments,  
2 which should be made to ensure piping and structural  
3 integrity. Defects, cracks or potential areas for  
4 such will be thoroughly analysed automatically and  
5 the system fatigue life will be produced  
6 automatically. This will lead to a prescribed  
7 inspection and repair intervals, plus quantified  
8 plant life. The assessments will include all  
9 loadings such as process, mechanical and  
10 environmental loadings. The potential for "leak  
11 before break" will also be assessed.

12  
13 A further module is the AP-Tech (acoustic pulsation  
14 technology). AP-Tech is an analysis, monitoring and  
15 assessment system to monitor, predict, simulate and  
16 assess the effects and levels of acoustic energy  
17 waves and frequencies in process plant piping  
18 systems. It also assesses the levels of dynamic  
19 excitation and vibration of the piping system but  
20 also has a module to prevent and identify a solution  
21 to the majority of small bore bench connection  
22 stress, vibration and fatigue problems. AP-Tech  
23 quantifies the piping system integrity, assesses the  
24 effects of all pulsation and piping behaviour,  
25 dynamic and fluid loadings, stresses, defects and  
26 small bore branches and predicts inspection and  
27 repair intervals as well as plant life and safety.  
28 These are all done "on-line", "live" or as a  
29 "continuous monitoring system". The AP-Tech system  
30 would constantly measure life acoustic pulsation  
31 pressure waves and the associated frequency and  
32 vibration values effected by acoustic pulsation and

1 vibration, etc. The detailed dynamic loading update  
2 will then be performed and the pipework will undergo  
3 an automatic and complete dynamic finite element  
4 stress analysis. Moreover, error estimation  
5 techniques will be used in order to determine the  
6 degree of accuracy. AP-Tech will use either a  
7 pressure transducer or a non-intrusive method to  
8 measure acoustic pulsations. The system will be  
9 dynamically assessed, the acoustic pulsation  
10 simulated and the acoustic-dynamic-vibration load  
11 cycle pattern and subsequent fatigue life will be  
12 determined. A computational fluid dynamic simulator  
13 will optionally be attached to allow a user to  
14 "visualise" the acoustic pulsation behaviour of the  
15 system. All necessary timescales and indications of  
16 work areas required will be produced "automatically  
17 which should be made to ensure piping and structural  
18 integrity. Defects, cracks or potential for such  
19 will be thoroughly analysed automatically and the  
20 system fatigue life will be produced automatically,  
21 which will lead to prescribed inspection and repair  
22 intervals, plus a quantified plant life. All  
23 loadings, including process, mechanical, pulsation,  
24 acoustic, vibration and environmental loadings will  
25 be included in the assessment.

26  
27 A further module to be used in the system is F-Tech.  
28 This is a module which provides beneficial analysis  
29 and monitoring and assessment for the majority of  
30 piping and vessel-tank flange connections. The  
31 problems to monitor involve stress, vibration,  
32 leakage and fatigue. F-Tech quantifies the flange

1 joint integrity, assesses the effects of all flange  
2 loadings, gaskets, bolts, stresses and predicts  
3 inspection and repair intervals as well as plant  
4 life and safety. This is all done "on-line", "live"  
5 or as "continuous monitoring" system. F-Tech will  
6 provide a detailed geometric update of the monitored  
7 area and then the area will undergo an automatic and  
8 complete finite element stress analysis and advanced  
9 error estimation techniques to determine the degree  
10 of accuracy. Flange displacement and rotation will  
11 be assessed along with gasket seating pressure in a  
12 live and automatic mode. This will be thoroughly  
13 analysed "automatically" and the system fatigue  
14 life, joint relaxation plus potential for joint  
15 leverage will be automatically produced. This will  
16 lead to prescribed inspection and repair intervals,  
17 plus quantified plant life. All loadings including  
18 process, mechanical and environmental loadings will  
19 be included in the assessment.

20  
21 A further module to be used is called Trans-Tech.  
22 This module is adapted to monitor, predict, simulate  
23 and assess the effects of the majority of piping  
24 transient events such as fluid transient and energy  
25 waves and frequencies in process plants piping  
26 systems. It also assesses the levels of dynamic  
27 excitation and vibration of the piping system.  
28 Moreover, Trans-Tech has a module to prevent and  
29 identify a solution to the majority of small bore  
30 branch connections stress, vibration and fatigue  
31 problems. Trans-Tech quantifies the piping system  
32 integrity, assesses the effects of all fluid

1 transient and piping behaviour, dynamic and fluid  
2 loadings, stresses, defects, small bore branches and  
3 thereafter predicts inspection and repair intervals  
4 as well as plant life and safety. This is all done  
5 "on-line", "live" or as a "continuous monitoring"  
6 system. A computation fluid dynamic simulator will  
7 optionally be attached to allow clients to visualise  
8 the acoustic pulsation behaviour of the system. All  
9 necessary timescales and indications of work areas  
10 required will be produced automatically which should  
11 be made to ensure piping and structural integrity.

12  
13 All six modules, described above, have the option of  
14 utilising accelerometers to include the effects of  
15 system vibration. All systems have preset intervals  
16 for the automatic measurement readings and  
17 subsequent re-analysis. This is determined by the  
18 user and could be adapted in order to analyse and  
19 measure every hour all day, or any other time  
20 interval. The cost of the modular architectural  
21 software the Integri-Tech system can be set up for  
22 any structure, any piece of plant, pressure vessels,  
23 equipment, civil buildings, structures, ships and  
24 buried pipes.

25  
26 In order to collect the data to be processed by the  
27 software as described above the processing  
28 arrangement according to the present invention uses  
29 measurement hardware components which will include:

30  
31 Ultrasonic thickness, ultrasonic blanket thickness  
32 measuring devices, accelerometers, data transmittal

1 devices, data interface devices, acoustic  
2 measurement systems, pressure transducers, non-  
3 intrusive PVDF systems, pipe support load  
4 measurement cells, strain gauges, ground settlement  
5 gauges, gyroscopes and ship-vehicle motion devices,  
6 acoustic emission systems, patch corrosion  
7 measurement devices, radiography interfaces, MAP  
8 scan interfaces, intelligent pigging interfaces, and  
9 crack growth measurement devices.

10

11 The advantages of using the system according to the  
12 present invention include:

13

14 The generation of information to protect inspection  
15 and remedial action plans. Since all necessary  
16 information on the critical areas of a structure are  
17 known, the use of the system will lead to a  
18 reduction of risks and a reduction of inspection  
19 costs. Moreover, the system provides real time  
20 information on the integrity of the system, which  
21 enables prompt action if required.

22

23 In Fig 4 the possible advantages of the system  
24 according to the present invention are shown. Line  
25 X represents the amount of costs involved with a  
26 respective number of inspections. Line Y represents  
27 the relation between possible risks and the number  
28 of inspections. Line Z represents a modified  
29 relation between risks involved and the number of  
30 inspections when using the system according to the  
31 present invention.

32

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- 1 Fig 4 shows that using the system according to the
- 2 present invention will lead to a lower level of
- 3 risk, while at the same time the number of
- 4 inspections (meaning the costs involved as
- 5 inspections) will decrease.